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Prof. Frazer read parts of a correspondence which he had had with Mr. Meehan, respecting the local cause of change of color in autumn foliage.

A letter from Prof. Lauth, of Munich, was read, relating to his recent investigations and proposed publication of a new work on Egyptology.

Pending nominations, Nos. 878 to 882 and new nomination No. 883 were read.

Mr. Fraley, for the Finance Committee, reported that he had collected and paid over to the Treasurer, the quarterly interest on the Michaux Legacy due April 1, amounting to \$133.07.

A discussion on the Wooten process then took place, pending which the meeting was adjourned.

On Meteoric Fireballs seen in the United States during the year ending March 31, 1879. By Professor Daniel Kirkwood.*

(Read before the American Philosophical Society, May 2, 1879.)

The following paper does not claim to present a complete list of the fire-balls which have appeared in our entire country during the last twelve months. It includes, however, all that have been brought to the writer's notice. Of those described only three can be certainly classed as detonating meteors, and in no case has an explosion been followed by a fall of meteoric stones; at least, no aerolites have been actually discovered.

(1.) 1878, June 3, 2h. 59m., A. M.—This meteor, observed at Chicago, by Prof. E. Colbert, was about equal in apparant magnitude to the moon at four days old. Its course was from near the zenith to a point about 4° above Beta Cassiopeiae. Near Alpha Cassiopeiae it exploded into seven or eight fragments.†

(2.) 1878, June 6th, 9h. 25m. (local time).—On the evening of June 6, Mr. Geo. H. E. Trouvelot, at Cambridge, Mass., saw a very large meteor which passed directly over Omicron Ursæ Majoris, and disappeared just below Eta in the same constellation. It was pear-shaped, the greatest and least diameters being in the ratio of 4 to 3, and it left behind it a long bright train. About three or four seconds after its appearance it burst into five

* No. 6 (January 20, 1877) of the fireballs described in my paper read before the A. P. S., March 16, 1877, was found, after the article was in type, to be a newspaper hoax.

† Letter from Prof. E. Colbert, dated June 3, 1878. See also the Sci. Obs. for July, 1878, p. 3.

or six fragments, each of which assumed the same form as the original meteor. "The preceding portion was of a crimson red hue, quite brilliant, and not dissimilar to the Strontian flame. The following portion was of a bluish violet color, which merged into that of the trail. This latter was composed of globules, each succeeding following one being of a more and more subdued violet, and finally not distinguishable from the color of the sky."*

(3.) 1878, August 11, 10h. 10m. (Indianapolis time).—A few minutes after 10 o'clock on Sunday evening, Aug. 11, Rev. John A. Bower, of Bloomington, Indiana, saw a large meteor near the eastern horizon. Mr. B. had just taken a position facing an eastern window. The meteor when first seen was almost exactly east of Bloomington, perhaps two or three degrees south of east, and 10° above the horizon. Its motion was from south to north, and the length of its apparent track was 20° or 25° . The first half of its course was but slightly inclined to the earth's surface; the inclination, however, became sensibly greater towards the point of disappearance, which was N. about 70° E., and very near the horizon. The apparent diameter of the meteor was about one-third that of the moon. The motion was extremely rapid; the time of flight not exceeding two seconds. No detonation was heard at Bloomington, nor was the meteor seen to separate into fragments at the time of disappearance.

The observations of Mr. Bower were given me verbally. To verify their accuracy I placed myself in the position which he occupied, and had him point out the meteor's course as he had seen it. The foregoing statement, I am satisfied, must be very nearly correct, except as to the time of flight, which is admitted by the observer to be very uncertain.

The same meteor is supposed to be described in the following telegrams which appeared in the newspapers of the next Tuesday morning:—"Titusville, Crawford Co., Pa., August 12. A beautiful meteoric display was witnessed from here last evening. The meteor made its appearance in the west at 10.30, moving in a northerly direction. It was of a greenish color and shone with great brilliancy, lighting up the entire surrounding country with a light that for the time prevailed over that of the full moon. Its appearance was only momentary, when it burst and divided into three fragments, two of which assumed a reddish color. Calculating from the time the explosion was seen until it was heard, the meteor was about 25 miles distant." "Oil City, Venango Co., Pa., August 12. A meteor of unusual brilliancy passed here last evening a few minutes after 10 o'clock. It was nearly twice the size of a cannon ball. Its course was north."

All accounts agree that the meteor's course was northward. It was seen to the west of Titusville; and as the final explosion occurred about 25 miles from that city we may conclude that the track terminated over Crawford County, Pa. The observations at Bloomington, Indiana, indicate that the body first became visible over West Virginia. The distance directly east from Bloomington to the meridian which bounds Venango County, Pa., on the west, is 348 miles. Hence the meteor's altitude when first

* Science Obs., June, 1878.

seen was about 77 miles. This, it must be admitted, is somewhat uncertain, but we may safely conclude that it was not less than 70 miles nor more than 85. The length of the visible track was between 160 and 175 miles. The estimated time of flight was probably too short; but the great velocity appears to indicate a hyperbolic orbit.

(4.) 1878, September 16, 9h. 0m., P. M.—This meteor was observed by Mr. Benjamin Vail, of Henryville, Clark County, Indiana. It was first seen near Gamma Ursæ Majoris, and it passed over Delta in the same constellation. Its apparent diameter was about one-fourth or one-fifth that of the moon.*

(5.) 1878, November 12, 7h. 0m., P. M. (local time.)—Washington, Indiana. Mr. D. Eckley Hunter, Principal of the High School, of Washington, Daviess County, Indiana, was, with several of his students, watching for shooting stars on the evening of November 12, when precisely as the town clock was striking seven, a large fireball appeared very close to Vega, passed in a southerly direction through the milky-way, and disappeared about 20° N. W. of Jupiter. Its motion was very slow; the time of visibility being estimated by Mr. Hunter at 10 seconds. Its apparent diameter was about two-thirds that of the moon. What struck Mr. Hunter as especially remarkable was the sharply defined disk which the meteor presented, up almost to the very moment of its disappearance.†

(6.) 1878, November 14, 3h. 30m., P. M.—In the New York Semi-Weekly *Tribune*, of December 10, 1878, Mr. Thomas Whitaker, of Hillside Farm, Mass., reports the appearance of this brilliant meteor as observed by himself. The sky was very clear at the time, and the meteor was seen in bright sunshine. It was due south from the place of observation.

(7.) 1878, December 30.—A few minutes before 7 o'clock (Indianapolis time) on the evening of December 30, 1878, a large meteor was seen in Indiana, Ohio, and Pennsylvania. So far, however, as known to the writer, the only observations sufficiently precise to be available in determining the height and direction of its path were made at Anderson, Madison County, Indiana; Washington, Washington County, Pa., and Wooster, Wayne County, Ohio.

Anderson, Indiana, Lat. 40° 5', Long. 8° 28' W.—The observations at Anderson were made by Mr. Frederick E. Dickinson, a member of the Senior Class, in Indiana University.‡ Mr. D. was in the street, walking eastward, when the meteor appeared in front of him, a few degrees N. of E., at an altitude of not less than 15° nor more than 17°. As the meteor passed behind a building the point of disappearance could not be determined. The apparent diameter was one-fourth that of the moon, and the time of flight was estimated at two seconds or probably a fraction less.

Washington, Pa., Lat. 40° 10', Long. 3° 12' W.—The phenomenon as

* Letter from Mr. Vail.

† Letter from Mr. D. E. Hunter.

‡ The meteor was seen by others in Indiana, but the descriptions given were nothing more than vague guesses in regard to its size and general direction.

seen in Washington, is described in the following letter from the Professor of Mathematics in Washington and Jefferson College :

“WASHINGTON, PA., February 1, 1879.

“PROF. D. KIRKWOOD, *Dear Sir*:—The fact of the appearance of a meteor here some time ago, may be of interest to you. I set down the facts as I learned them at the time, and intended to have written you sooner. About 7 P. M., Washington, Pa. time, December 30th, a brilliant meteor was seen here. The account which I have was given me by a young man, Mr. A. M. Gow, Jr., who has given me, I have no doubt, a very fair statement of what was to be seen at that time. He was walking eastward on the south side of the street, so that he was in the shade of the buildings; the moon shining brightly at the time. Suddenly a light shone about him as if an additional lamp had been lighted close behind him. He did not turn immediately to look, but when he did he saw a meteor about the size of the moon as he thought by comparing his impression with the half-full moon immediately afterwards. It was of a slightly greenish color, but just as it disappeared it became reddish. The place in which he saw it, as far as I can judge, was about Alpha Cygni, and the place of its disappearance was about Alpha Lyræ. If so, you see its course was W. N. W., and it was observed through 24° of its path. The meteor had been visible a little time, however, before Mr. Gow turned to look. It was seen by three others here that I know of. Yours Truly,

“D. J. McADAM.”

Observations at Wooster, Lat. $40^{\circ} 50' N.$, Long. $4^{\circ} 56' W.$ —Professor Samuel J. Kirkwood, of Wooster University, had a good view of the meteor, which he describes as the most brilliant he has ever seen. It was greatly elongated, and the apparent diameter at right angles to its path was half that of the moon. The point of the meteor's first appearance and also the first part of its track were accurately observed through large tree-tops.* Prof. Kirkwood gives the following angles as the result of careful measurement with a surveyor's transit :

“First appearance, east, alt. 50° . Disappearance, S. 13° E. alt. 13° .” Prof. K. remarks : “The first appearance is, I am satisfied, quite exact, and entirely reliable. I am not so confident of the observation at disappearance. The meteor exploded when about S. 33° E.”†

According to the observations at Wooster and Anderson the meteor became visible at a height of 72 miles over a point in Columbiana County, Ohio, Lat. $40^{\circ} 50'$, Long. $3^{\circ} 40' W.$ The Wooster and Washington observations, seem incompatible; the latter, however, make no claim to strict accuracy. As the explosion seen at Wooster was not observed either at Washington or Anderson it is probable that at these greater distances the disappearance was simultaneous with the separation into fragments. Such doubtless has been the case in several other instances. For example, the

* A member of the Junior Class in Wooster University was with Prof. Kirkwood.

† Letter from Prof. S. J. Kirkwood.

fragments of the meteor of August 11, 1878, seen at Titusville, Pa., were invisible at Bloomington, Indiana. If we assume, then, that as seen from Washington the point of explosion was also that of disappearance, we find by a tentative process that the observations are approximately satisfied by supposing the separation to have taken place over Tuscarawas County, Ohio, about N. 80° W. from Washington, Pa., at a distance of 70 miles, and at a height of 17 or 18 miles above the earth's surface. After the explosion the parts remained visible at Wooster until within 12 or 13 miles of the earth. The course was nearly S. W.; the true length of the entire visible track as seen at Wooster was about 85 miles; that of its projection on the earth's surface, about 60 miles. The inclination of the path to the surface of the earth was about 45°. The velocity, though uncertain, was probably greater than that corresponding to an elliptic orbit. No detonation was heard at any point of observation.

(8.) 1879, January 28, 2h. 28m., A. M., local time.—Observations at Princeton, Green Lake County, Wisconsin. Lat. 43° 50' N., Long. 12° 13' W.—Rev. William M. Richards, states that between 2 and 3 o'clock* on the morning of January 28, he was awakened by a sudden flash of intense light which he at first supposed to be lightning. It continued, however, for some seconds, and by the time he was thoroughly awake and ready to make observations the light had assumed a reddish tinge, somewhat resembling that of a Roman candle. He next supposed it to be a fire, but immediately found that if so, it must be out of the village. After making other conjectures, to be as quickly dismissed, he finally reach the conclusion that the light was meteoric.

“By that time,” he says, “the frightful conflagration had settled down into a low pyramid of lurid light, the base extending 60° along the N. E. horizon, and the vertex having an altitude of 30°. * * * The time of the meteor's flight is very uncertain; perhaps 8 to 10 seconds. The brilliant and white light at first would indicate that the movement was from the West.”†

Observations at Traverse City, Michigan, Lat. 44° 43' N., Long. 8° 40' W. The *Grand Traverse Herald*, of January 30, 1879, states that the accounts of this meteor by different observers were, in some respects, very conflicting; those who saw it being too much startled to observe it closely. “What is known is that it was an immense ball of fire, that the darkness was made light as noonday, and that a terrible explosion followed its disappearance. A night watchman who saw it explode says it flew into minute pieces like star dust. The one thing that all agree upon is the explosion. This was heard with equal clearness at Mayfield, 13 miles south of Traverse City, and at Williamsburg, 12 miles east. The effect was like that of an earthquake. Houses were jarred, windows shook, and dishes rattled upon the shelves. A swaying motion seemed to be given to the

* Mr. Richards did not notice the *exact* time. The Michigan observations give 2h. 28m.

† Letter from Rev. Mr. Richards. See also the *Sci. Am.* of March 15, 1879.

buildings as an upheaval and settling back. If the meteor had not been seen it would have been thought an earthquake shock."

In response to a letter of inquiry, Thomas T. Bates, Esq., editor of the *Grand Traverse Herald*, has given me the following additional statement :

"A night watch on our streets, an intelligent, cool-headed man, gives me in substance this : Was on watch ; passing from due west to east ; saw a great light ; turned quickly and saw a ball of fire over my right shoulder ; turned to left and watched it until it disappeared ; when first seen it appeared about as high as ordinary rain clouds ; was on a down grade close to and apparently over the bay ; came from S. W. and passed to N. E. ; appeared to me larger than full moon ; full moon looks to me to be 18 or 20 inches in diameter ; meteor appeared to pass me, and move out of sight at about the rate of speed a descending rocket has after its explosion ; had a good chance to see it plainly ; just after passing me a singular thing occurred ; a ring of fire seemed to peel off the meteor itself, and this followed the ball of fire out of sight, but dropped a little behind it. It was perfectly distinct, and appeared to be hollow, for I could see a dark centre. Every thing was as light as day. I looked at my watch as it disappeared ; it was just 28 minutes after 2 o'clock. I passed on my beat, and shortly the terrific explosion came. It shook and jarred every thing around. I immediately looked at my watch, and it was 32 minutes after 2.

"This is his report as it was given the next day, and as it was repeated to me a few days ago. I have no idea that the meteor fell into Carp Lake,* or that even a portion of it fell there. Every thing points to the correctness of Mr. Smith's report which I send you.

"Truly yours,

"THOS. T. BATES."

Charlevoix, Charlevoix County, Michigan, Lat. 45° 15' N., Long 8° 12' W. Willard A. Smith, Esq., editor of the *Charlevoix Sentinel* states that the meteor was seen by several persons at Charlevoix, where it appeared to be at least four times as large as the full moon ; that it burst almost exactly over the village, and that parts of it were seen to fall. The ground was covered with deep snow, which was disturbed in several spots by the meteorites, though strangely enough no fragments were found. The meteor before striking the earth lighted up surrounding objects with an intensity of brightness surpassing that of sunshine, and its explosion resembled the sound of musketry. Its direction was nearly from S. W. to N. E., and the interval was very brief between the explosion and report.†

Cheboygan, Michigan, Lat. 45° 37' N., Long. 7° 31' W. Mr. and Mrs. Jacob Walton, of Cheboygan, both saw the meteoric light as it approached from the S. W. It lasted several seconds, and was so bright as to cast a very distinct shadow into the windows from the roof of the porch. From

*It was reported that a hole through the ice on Carp Lake had been discovered the next day, indicating that the aerolite had probably fallen into the lake.

†Condensed from a letter of Mr. Smith to Mr. Bates.

this shadow Mr. Walton estimated the greatest altitude of the meteor at about 45° . The explosion was not heard at Cheboygan.*

The preceding observations indicate that the meteor's course was approximately N. E. by N., and that it first became visible over a point not far from Lat. $44^{\circ} 25' N$, Long. $9^{\circ} 0' W$. The distance from Traverse city to the point at which meteoric matter is said to have fallen is about 42 miles. But the interval of four minutes between the observed explosion and the report corresponds to a distance of about 49 miles. This would make the point of explosion 26 miles above the earth's surface. The height at first appearance, if we can rely upon the rather uncertain estimate of Mr. Walton, at Cheboygan, must have been nearly 100 miles. The true length of the visible track was about 124 miles, and the length of its projection on the earth's surface, 66 miles. The time of flight is very uncertain, though the observations indicate a rather slow motion.

(9.) 1879, February 3, 11h. 30m., P. M. Indianapolis time.—This meteor is thus described by a correspondent of the Indianapolis *Daily News* for February 7 :

"Raysville [Henry County], Indiana, February 4, 1879. Last night between 11 and 12 o'clock was seen, by a few citizens of this place, one of the largest and most brilliant meteors ever observed in this section. It was larger than the one seen in December, 1876, but did not last so long, being but a few seconds in view. It apparently rose from the eastern horizon, and advanced rapidly, marking its path by a stream of flame until it had almost reached the zenith, when it exploded with a dull but plainly audible report. The different parts shot earthward in various directions, but the lights of all were extinguished before they had gone very far."

(10.) 1879, February 17, 8h. 0m., P. M., Chicago time.—This meteor was observed by C. A. Kenoston, Professor of Mathematics and Astronomy in Ripon College, Wisconsin. It was first seen in the West at an altitude of about 30° . It moved slowly along the line of the two southern stars in the square of Pegasus and disappeared near the horizon without any audible explosion. It was very bright—increasingly so—and seemed to have a short tail.†

(11.) 1879, February 20, 10h. 45m., P. M.—This meteor was seen at Henryville, Clark County, Indiana, by Mr. Benjamin Vail. A brilliant train remained visible nearly a minute after the meteor itself had disappeared.‡

(12.) 1879, March 15, 3h. 53m., A. M.—This meteor was observed by a number of persons at Washington, Daviess County, Indiana. When first seen it was S. $10^{\circ} W$., at an altitude of 25° . It moved westward 20° and then burst into many fragments. The meteor was of a pale bluish color, but when it exploded it lighted up everything almost like daylight.

* Letter from C. S. Ramsay, Esq., to Mr. T. T. Bates.

† Letter from Prof. Kenoston.

‡ Thus briefly referred to in a letter from Mr. Vail. No further description was given.

A luminous cloud of smoke or vapor remained visible several minutes after the explosion. No sound was noticed.*

REMARKS.

As already stated, no meteorites are known to have fallen from any of the fireballs in the preceding list; although in more than one case the disappearance was followed by loud detonations, and the explosion of the meteor of February 3 took place near the zenith of the principal point of observation. It is also remarkable that the only two whose velocities could be approximately determined were almost certainly moving in hyperbolic orbits. This last mentioned fact is in harmony with the theory of Professor Von Neissl, who regards aerolitic and denotating meteors as a distinct class of cosmical bodies, differing both from comets and periodic star showers in the original velocities with which they enter the sphere of the Sun's attraction.† But not only have certain comets moved in hyperbolas but the computed velocities of at least a few bolides have undoubtedly indicated elliptic motion. This theory therefore can hardly be accepted without further confirmation.

Are meteoroids moving in hyperbolas to be regarded in general as fragments of disintegrated comets?—The discovery that the meteors of November 14, November 27, April 20, and August 10, are intimately connected with comets moving in the same orbits, has suggested that *all* shooting stars and meteoric fire-balls may have been produced by the gradual dissolution of comets or cometary clusters. It must be remembered, however, that the comets connected with these meteor streams are all periodic, and that the dispersion of their matter is due to an indefinite number of returns to perihelion. In cases of non-periodicity complete dissolution, as the result of a single perihelion passage, would be extremely improbable. We conclude therefore, that the meteor of December 30, 1878, and others with hyperbolic orbits are *not* cometary fragments dissevered by solar influence.

That some fireballs explode noiselessly, while others, apparently no larger, produce loud detonations, is a remarkable fact not hitherto explained. The fact also that explosions very often occur without being followed by the fall of aerolites seems no less mysterious. Professor Newton has suggested that aerolites are probably furnished only by such meteors as penetrate the atmosphere with relatively slow motions; those moving with great velocities being burnt up or dissipated before reaching the earth's surface. Much, however, must evidently depend on the size and constitution of the meteoroids. Small meteors (shooting stars) are entirely consumed in the atmosphere. The composition and structure of meteoric stones are very widely various. "While some are extremely hard, others are of such a nature as to be easily reducible to powder. It is not impossible that when some of the latter class explode in the atmosphere they may be completely pulverized, so that, reaching the earth in minute particles, they are never

* Letter from Prof. D. E. Hunter.

† See the Report on Luminous Meteors by a Committee of the Brit. Assoc. for the Adv. of Sci. for 1877.

discovered." * The fireballs of August 11 and December 30, 1878, as well as that of February 3, 1879, had very rapid motions, and we can perhaps best account for the non-appearance of aerolites on the theory of their complete disintegration.† The meteors, it is obvious, could not have escaped out of the atmosphere. Events of this kind are doubtless of very rare occurrence. We have, it is believed, no authenticated instance in which a fireball has escaped after approaching within 39 miles of the earth's surface.‡ Assuming this as an inferior limit and taking 100 miles as the greatest height at which such bodies become visible, it is easy to show that but one in thirty-four can continue its orbital motion.

SUGGESTION TO OBSERVERS.

In the theory of meteors it is a matter of first importance to determine the form of their orbits. If any move in hyperbolas they must have had a proper motion in space before entering the solar system. Now the nature of a meteor's orbit is determined from its observed velocity. Unfortunately, however, the time of flight (on which the velocity depends) is generally a very uncertain element; the estimates of different observers being very discordant. Persons therefore who report such phenomena should train themselves to habits of exactness in measuring the time of visibility.

Stated Meeting, May 16, 1879.

Present, 28 members.

Vice-President, Mr. FRALEY, in the Chair.

A letter of envoy was received from Mr. A. Agassiz.

A letter of invitation to the members to attend the last session, May 9th, of the West Chester Philosophical Society was received.

Donations for the Library were received from the editor of the *Zoologischer Anzeiger*, Leipzig; M. Melsens, Brussels; the *Annales des Mines*, Paris; Meteorological and Antiquarian Societies, Cobden Club, and *Nature*, London;

* Met. Astr., p. 65.

† The average height of shooting stars at extinction is about 55 miles; that of aerolitic fireballs and detonating meteors at the time of explosion, about 25 miles.

‡ This was the nearest approach of the great meteor of July 20, 1860. See Prof. Coffin's memoir in the *Smithsonian Contributions*, vol. XVI.